ELSEVIER

Journal of Arid Environments 69 (2007) 432–440

Journal of Arid Environments

www.elsevier.com/locate/jaridenv

Reducing *Euphorbia esula* with a combination of sheep grazing and imazapic

S.S. Seefeldt*, J.B. Taylor, S. Van Vleet

United States Department of Agriculture, Agricultural Research Service, United States Sheep Experiment Station, 19 Office Loop, Dubois, ID 83423 USA

Received 7 March 2006; received in revised form 4 October 2006; accepted 12 October 2006
Available online 28 November 2006

Abstract

Field studies were conducted in Idaho from 2002 to 2004 to determine whether summer grazing of sheep for 1 or 2 years before an autumn application of imazapic would enhance control of *Euphorbia esula*. *E. esula*, a perennial plant native to parts of Europe and Asia, has invaded the Great Plains and Rocky Mountains after its introduction into North America in the early 1880s and caused significant reductions in native plant biomass. Experiments were conducted to determine the impacts of 1 or 2 years of sheep grazing with or without a fall application of imazapic on *E. esula* and native plant populations. Sheep grazing was designed to remove reproductive parts from *E. esula* within a 10 d grazing period. Imazapic was applied at 210 g ae ha^{-1} with 1.25% (v/v) methylated seed oil. One year of sheep grazing did not alter measured vegetation components, but it did result in an increase of grass seed in the soil. Two years of sheep grazing increased the forb and grass cover component, increased the grass seed in the soil, and kept the *E. esula* seed bank from increasing. Application of imazapic reduced *E. esula* stem densities and cover and increased native forb cover. The combination of 1 or 2 years of sheep grazing and imazapic did not enhance the control of *E. esula*. However, 2 years of carefully timed sheep grazing followed with an imazapic application resulted in sustained productivity of plant biomass in the pasture. Because 2 years of sheep grazing prevented an increase in the *E. esula* seed bank, managers may have a better opportunity to establish desired vegetation in sagebrush steppe ecosystems after removing *E. esula* with imazapic.
Published by Elsevier Ltd.

Keywords: Biocontrol; Herbicide; Integrated management

*Corresponding author. United States Department of Agriculture, Agricultural Research Service, Subarctic Agricultural Research Unit, Room 355 O'Neill Building, University of Alaska Fairbanks, Fairbanks, AK 99775 USA. Tel.: +1 907 474 1898; fax: +1 907 474 1813.

E-mail addresses: sseefeldt@pw.ars.usda.gov (S.S. Seefeldt), btaylor@pw.ars.usda.gov (J.B. Taylor), svanvleet@wsu.edu (S. Van Vleet).

0140-1963/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.jaridenv.2006.10.007

1. Introduction

Euphorbia esula, a perennial plant native to parts of Europe and Asia, has invaded the Great Plains and Rocky Mountains after its introduction into North America in the early 1880s (http://www.nps.gov/plants/alien/fact/eues1.htm). As the range of *E. esula* has expanded, efforts to control it have increased. *E. esula*, which cattle will not graze, can reduce herbage production over 75% (Lym and Kirby, 1987). Herbicides are effective for *E. esula* management (Markle and Lym, 2001), but they are expensive and only cost effective when the infestation is dense and the pasture is productive (Lym and Kirby, 1987; Messersmith, 1990; Lym and Messersmith, 1994). Several insect biocontrol agents have been introduced to reduce *E. esula* infestations (Anderson et al., 2000) with varying levels of success.

Sheep and goats are an effective biocontrol agent for the management of both sparse and dense *E. esula* infestations (Landgraf et al., 1984; Walker et al., 1992; Olson et al., 1996; Lym et al., 1997) and after an adaptation period, they will select up to 50% of their diet as *E. esula* (Walker et al., 1992). In the Intermountain West, the nutrient quality of *E. esula* is usually greater than the nutrient quality of many native grasses throughout the summer grazing season (Olson et al., 1996), which can favor sheep selection of *E. esula* over other plant species during late summer. Sheep or goat grazing alone will not completely remove *E. esula* from an infested pasture; however, the timing and intensity of sheep grazing can be managed to reduce *E. esula* seed productivity while having minimal impacts on desired vegetation (Lym et al., 1997; Olson and Wallander, 1998; Taylor et al., 2005).

Imazapic, an acetolactate synthase inhibitor, is registered for control of *E. esula* in rangelands. Imazapic should be applied in the autumn for maximum efficacy (Markle and Lym, 2001). Thus the application will occur after the plant has produced and shed seed. Imazapic may have enough soil residual activity to inhibit some *E. esula* seedlings the following spring (Joe Vollmer, personal communication) however research in this area has not been conducted. The combination of sheep grazing timed to prevent seed production, followed with an imazapic application, may reduce *E. esula* more than an imazapic application alone. The objectives of this study were to determine whether pasture biomass, stem densities of *E. esula*, and cover of *E. esula*, grasses, and forbs are altered when 1 or 2 years of sheep grazing is combined with fall application of imazapic, compared with grazing or imazapic application alone; and to determine whether or not sheep grazing to prevent *E. esula* seed production would result in a reduced *E. esula* seed bank. Our hypothesis is that the combination of sheep grazing and imazapic would increase the control of *E. esula*, compared with either sheep grazing or imazapic alone.

2. Study site

The study area was located 2 km east of Spencer, Idaho near Peppermint Creek (112°10′W, 44°21′N) at an elevation of 1800 m in the north-eastern part of the sagebrush steppe region (West, 1983). Soils are gravelly loam, mixed, frigid Calcic Argixerolls derived from wind-blown loess, residuum, or alluvium on slopes ranging from 0% to 2% (Natural Resources Conservation Service, 1995). Climate is semi-arid with cold winters having several months of mean temperatures below freezing, and warm summers having several months of daily highs averaging 27 °C. Annual precipitation was 264, 312, and 414 mm in

2002, 2003, and 2004, respectively, with up to 70% falling in the winter as snow. *Artemisia tridentata* ssp. *vaseyana*, *E. esula*, *Festuca idahoensis*, *Pseudoroegneria spicata* ssp. *spicata*, and *Calamogrostis montanensis* dominated the vegetation.

3. Methods

In the spring of 2002, the *A. tridentata* ssp. *vaseyana* canopy was mowed to reduce uneven competition for resources between *A. tridentata* ssp. *vaseyana* and *E. esula*. Two experiments were set up; experiment one began in 2002 and experiment two began in 2003. Experiment one was fenced into 16 plots, each with a dimension of 25×25 m, and incorporated 2 years of sheep grazing. Experiment two was placed 50 m south of the experiment one. Experiment two was fenced into 16 plots, each with a dimension of 20×20 m, and incorporated 1 year of sheep grazing. In both years experimental plots were arranged in a 2×8 plot formation with the long side aligned north to south. In experiment one, plots were arranged in a randomized complete block design with four replications along the north to south gradient. In experiment two, *E. esula* cover served as the blocking factor as there was not a uniformly dense stand of *E. esula*. The treatments were: (1) ungrazed + no imazapic application; (2) grazed + no imazapic application; (3) ungrazed + imazapic application; and (4) grazed + imazapic application.

To implement the grazing treatment, ewes (nonpregnant and nonlactating; Columbia, Polypay, Rambouillet, and Targhee breeds; body weight = 78 ± 7 kg [standard deviation]; age = 2–4 year) were allowed to graze the respective plots. Stocking rates for each plot varied and were adjusted to ensure the removal of all *E. esula* reproductive parts within a 10 d period. Grazing occurred in early June each year when most *E. esula* plants had yellow bracts and seeds were not past the milk stage.

Imazapic was applied at 210 g ae ha^{-1} with 1.25% (v/v) methylated seed oil[1] in mid-August, 2003. *E. esula* was actively growing, 4–45 cm tall in grazed pastures and 30–60 cm tall in ungrazed pastures, providing the leaf material needed for adequate herbicide interception and translocation to the roots. A CO_2 backpack-sprayer was used to apply the imazapic at 5 km h^{-1}, calibrated to deliver 190 L ha^{-1} at 345 kPa. The spray boom was 3 m wide with six 11002 A.I. flat fan tips. At the time of application, temperature varied from 35 to 37 °C, relative humidity from 8 to 20%, and wind speed from 0 to 4 m s^{-1}. A 3-m strip was sprayed around the outside of all pastures to reduce *E. esula* seed rain into the pastures.

Vegetation measurements were taken each year at sixteen 0.18 m^2 permanent quadrats that were placed in an equally spaced 4×4 grid in each experimental plot. All quadrats were at least 3 m from the fence to prevent seed rain from neighboring plots. Before grazing each year and in the year following imazapic application, pasture biomass was determined, *E. esula* stem density was counted, and cover of *E. esula*, grasses, and forbs was visually estimated. Pasture biomass was determined using a Model 18-3000 impedance meter.[2] Ten 0.18 m^2 areas outside the study area with a wide range of *E. esula* infestations were identified for calibration of the meter. To calibrate the meter, *E. esula* stems were counted; cover of *E. esula*, grasses, and forbs was visually estimated; impedance was

[1]Loveland Industries, P.O. Box 1289, Greely, CO 80632, USA.
[2]Neal Electronics, 544 North Myers Street, Burbank, CA 91506, USA.

measured; and plants were clipped at ground level and separated into *E. esula*, grasses, or forbs. The clipped vegetation was dried for 48 h at 60 °C and weighed.

In experiment one only, soil samples were collected (40, 5-cm diameter × 5-cm depth cores/plot) at the end of each grazing season, but before imazapic treatment. The 40 cores from each sample were combined, dried (40 °C for 24 h), and sieved to remove roots and rocks. A 1 kg soil sample was spread out in a plastic tray (27.5 × 53.5 × 6 cm) that had a 3 cm layer of potting mix[3] under a felt barrier. The soil was wetted from below and the tray placed in a growth chamber set to 20 °C, 12/12 h day/night, and 75% relative humidity for 35 d. Soils were watered as needed, and emerging *E. esula*, grass, or forbs were counted and removed twice a week.

Data used in the analysis are arithmetic means of the 16 quadrats in each plot. The data were determined to be normally distributed using a UNIVARIATE procedure on model residuals with the Shapiro–Wilk statistic (SAS Institute Inc., Cary, NC, 2004).

Experiment one and two vegetation data (plant biomass, *E. esula* stem density, *E. esula* cover, grass cover, and forb cover) were analyzed separately as randomized complete block designs using the General Linear Models procedures of SAS (SAS Institute Inc., Cary, NC, 2004) with treatments arranged in a 2 × 2 factorial array. Treatment factors were sheep grazing (grazed or ungrazed) and imazapic application (applied or not applied). The treatment factors and corresponding interaction were considered fixed effects and block was considered a random effect. A least significant difference means separation test was used when the *F*-test probability was <0.05. Seed bank data, comparing grazed and ungrazed treatments, were evaluated using ANOVA procedures (SAS Institute Inc., Cary, NC, 2004) and a least significant difference means separation test, when the *F*-test probability was <0.05. Calibration of the impedance meter was determined using linear regression. Regression analysis of plant dry weight and the impedance meter resulted in a linear response with an r^2 from 0.85 to 0.99, indicating that the impedance meter was useful for nondestructively estimating plant biomass.

4. Results

4.1. Pasture biomass

In experiment one, plant biomass was similar ($p = 0.24$–2.24) in all plots ($163\,\mathrm{g\,m^{-2}} \pm 14$ SE) before treatment application and following 1 year of sheep grazing ($173\,\mathrm{g\,m^{-2}} \pm 17$ SE). Neither sheep grazing for 2 years nor imazapic application influenced ($p = 0.53$) plant biomass ($106\,\mathrm{g\,m^{-2}} \pm 30$ SE) the following year.

In experiment two, initial plant biomass was different ($p = 0.02$) among plots. This difference was due to blocking for *E. esula* density ($p = 0.005$) where block 1 (greatest *E. esula* density) had greater biomass ($164\,\mathrm{g\,m^{-2}}$) than did blocks 2–4 (84, 80, and $62\,\mathrm{g\,m^{-2}}$, respectively) with an overall SE of $\pm 15\,\mathrm{g\,m^{-2}}$. In the year following sheep grazing and imazapic application, there were both sheep grazing ($p = 0.02$) and imazapic ($p = 0.0003$) effects on plant biomass. Ungrazed plots averaged $83\,\mathrm{g\,m^{-2}}$ whereas grazed plots averaged $61\,\mathrm{g\,m^{-2}}$ with an overall SE of $\pm 6\,\mathrm{g\,m^{-2}}$. Plots without an imazapic application averaged $94\,\mathrm{g\,m^{-2}}$ whereas plots with an imazapic application averaged $44\,\mathrm{g\,m^{-2}}$ with an overall SE of $\pm 6\,\mathrm{g\,m^{-2}}$. There was a weak interaction ($p = 0.06$) between sheep grazing and imazapic

[3]Ferti.lome Voluntary Purchasing Groups, Inc., Box 460, Bonham, TX 75418, USA.

Table 1
Impact of sheep grazing and/or imazapic application on total plant biomass in experiment two[a,b]

Treatment[c]	Year	
	2003	2004
	$g\,m^{-2}$	
Control	100 a	117 a
Sheep grazed	91 a	74 b
Imazapic applied	88 a	49 c
Sheep and Imazapic	111 a	43 c
SE	±15.4	±8.5

[a]Abbreviation: SE = standard error.

[b]Numbers within a column followed by the same letter are not significantly different at the 0.05 level according to a least significant difference test.

[c]Sheep grazing occurred in early June 2003, imazapic application occurred August 14, 2003, and vegetation measurements were conducted before sheep grazing in 2003 and in June 2004.

application (Table 1). The combination of imazapic application with sheep grazing decreased ($p<0.0007$) plant biomass compared to sheep grazing without imazapic application, and sheep grazing alone decreased ($p<0.003$) plant biomass compared to the control plots.

4.2. *E. esula* stem density and cover

In experiment one, *E. esula* stem density and cover were similar ($p = 0.29$–0.81) in all plots before treatment application (220 stems $m^{-2} \pm 29.4$ SE and 56% ± 3.3 SE, respectively) and following 1 year of grazing (229 stems $m^{-2} \pm 32.5$ SE and 67% ± 5.3 SE, respectively). In the year following imazapic application, imazapic application reduced ($p<0.01$) *E. esula* stem density (167 vs. 6 stems m^{-2}, respectively; SE of ± 12.4) and cover (44% vs. 4%, respectively; SE ± 17%). Sheep grazing for 2 years did not affect *E. esula* stem density or cover ($p = 0.64$ and 0.20, respectively). No interaction between imazapic application and sheep grazing was observed for *E. esula* stem density ($p = 0.89$) or *E. esula* cover ($p = 0.64$).

As with experiment one, *E. esula* density and cover in experiment two were similar ($p = 0.08$–0.22) in all plots before treatment (94 stems $m^{-2} \pm 29.1$ SE and 34% ± 5.1 SE, respectively). Fall imazapic application resulted in a reduction ($p<0.01$) in *E. esula* stem density (3 vs. 89 stems m^{-2}, ± 13 SE) and cover (2% vs. 29%, ± 9.8 SE) the following year compared to untreated plots.

4.3. Grass cover

In experiment one, grass cover was similar ($p = 0.28$–0.55) in all plots before treatment application (31% ± 2.9 SE) and after 1 year of sheep grazing (15% ± 3.1 SE). In the year following imazapic application, there was an effect of both sheep grazing ($p = 0.004$) and imazapic application ($p = 0.008$). Plots without sheep grazing averaged 42% grass cover, whereas plots with sheep grazing averaged 29% grass cover (SE ± 7.6). Plots without an

Table 2
Impact of sheep grazing and/or imazapic application on percentage grass cover in experiment one[a,b]

Treatment[c]	Year		
	2002	2003	2004
	% cover		
Control	35 a	13 a	30 b
Sheep grazed	32 a	18 a	29 b
Imazapic applied	32 a	12 a	53 a
Sheep and imazapic	26 a	18 a	28 b
SE	±2.9	±3.1	±3.3

[a]Abbreviation: SE = standard error.
[b]Numbers within a column followed by the same letter are not significantly different at the 0.05 level according to a least significant difference test.
[c]Sheep grazing occurred in early June 2002 and 2003, imazapic application occurred August 14, 2003, and vegetation measurements were conducted before sheep grazing in 2002 and 2003 and in June 2004.

imazapic application averaged 30% grass cover, whereas plots with an imazapic application averaged 41% grass cover (SE ± 7.6). A weak interaction ($p = 0.05$) between sheep grazing and imazapic application was observed. The imazapic application without grazing resulted in an increase ($p < 0.0001$) in grass cover compared to the other treatment combinations (Table 2).

In experiment two, grass cover was similar ($p = 0.07$–0.21) in all plots before (29% ± 3.6 SE) and after treatment application (34% ± 3.2 SE).

4.4. *Forb cover*

In experiment one, forb cover was similar ($p = 0.47$–0.54) in all plots before treatment application and following 1 year of grazing (13% ± 2.5 SE and 17% ± 3.1 SE, respectively). An effect of 2 years of sheep grazing ($p = 0.003$) and imazapic application ($p = 0.004$) was detected. Plots without sheep grazing averaged 24% forb cover, whereas plots with sheep grazing averaged 51% forb cover (SE ± 16) the following year. Plots without an imazapic application averaged 25% forb cover, whereas plots with an imazapic application averaged 50% forb cover (SE ± 16). An interaction between sheep grazing and imazapic application was not detected ($p = 0.21$).

In experiment two, forb cover was similar ($p = 0.19$) in all plots before treatment application (38% ± 7.2 SE). Fall application of imazapic increased ($p = 0.0008$) forb cover from 28% is 2003 to 55% in 2004 (SE ± 12.2%).

4.5. *Effect of sheep grazing on seed bank*

In experiment one, after 1 year of grazing, seed banks of *E. esula* ($p = 0.95$) and forbs ($p = 0.36$) were similar in the grazed and ungrazed treatments, but there were more grass seeds ($p = 0.04$) in the ungrazed plots compared to the grazed (Table 3). After a second year of grazing, seed banks of grass ($p = 0.05$) and *E. esula* ($p = 0.0004$) increased in the

Table 3
Impact of sheep grazing on seed banks after 1 and 2 years of sheep grazing in experiment one[a,b]

Treatment	*Euphorbia esula*		Grass		Forb	
	2002	2003	2002	2003	2002	2003
	Number m^{-2}					
Grazed	180 a	150 a	590 a	760 a	460 a	790 a
Ungrazed	180 a	590 b	890 b	1480 b	360 a	690 a
SE	±48	±66	±92	±232	±81	±81

[a]Abbreviations: SE, standard error.
[b]Numbers within a column followed by the same letter are not significantly different at the 0.05 level according to a least significant difference test.

ungrazed plots compared to grazed plots, whereas forb seed numbers did not change ($p = 0.47$).

5. Discussion and conclusions

Sheep grazing was timed to remove reproductive structures from the *E. esula* plant. This objective was achieved, but it also resulted in the consumption of grasses and forbs. Goat grazing probably would have resulted in less grass utilization, but would have required increased fencing costs (Walker et al., 1994). Most of the forb species had set seed and senesced before sheep grazing occurred, and forb cover doubled in the grazed plots as a response to removal of grass and *E. esula* biomass. Because of the short duration of grazing, many grasses were able to recover and produce seed before winter. One year of sheep grazing decreased the grass seed bank. A second year of sheep grazing in experiment one decreased the grass and increased the forb components of the pasture, increased the grass seed bank, and kept the *E. esula* seed bank from increasing. However, after the grazing treatments, *E. esula* did not recover enough to produce seed. In experiment two, sheep grazing for 1 year did not change any of the measured vegetation components. Similar to previous work (Olson and Wallander, 1998; Dahl et al., 2001), results from the two experiments indicate that sheep grazing alone will slowly alter vegetation components in a pasture infested with *E. esula*.

In experiments one and two, the application of imazapic resulted in a decrease of *E. esula* stem density and cover with a corresponding increase in forb cover. This decrease in *E. esula* is similar to that caused with the use of picloram (Lym et al., 1997), however in that study the impacts of the herbicide and grazing on other vegetation was not measured. In experiment one, imazapic application did not reduce overall plant biomass. With 2 years of rest from grazing, the grass components in experiment one had recovered enough to increase cover and replace *E. esula* biomass lost after the herbicide application. In experiment two, however, the imazapic application did reduce overall plant biomass as the grass and forb components had not developed enough to replace *E. esula* biomass lost after the herbicide application. Others have measured similar plant responses in *E. esula* infested pastures to imazapic (Markle and Lym, 2001) and to grazing (Olson and Wallander, 1998).

E. esula is an expanding exotic weed species in the arid lands of the sagebrush steppe as well as many other areas throughout North America (Lajeunesse et al., 1999). On arid lands and in large infestations of *E. esula*, multiple years of chemical control is not an economically viable option for land managers (Bangsund et al., 1996). Although *E. esula* is excellent forage for sheep and goats, sheep and goat grazing will not remove the plant from the ecosystem (Bowes and Thomas, 1978; Olson and Lacey, 1994). In this study, the combination of 1 or 2 years of sheep grazing followed with an imazapic application did not enhance the control of *E. esula* over imazapic alone. However, 2 years of carefully timed sheep grazing (just before seed set) and a stocking rate of 96 sheep ha^{-1} for 10 days prevented an increase in the *E. esula* seed bank and sustained plant biomass productivity in the pasture. This prevention of an increase in the *E. esula* seed bank, especially if *E. esula* seeds are aging and perhaps losing vigor, may give managers a better opportunity to establish desired vegetation after removing *E. esula* with imazapic.

Acknowledgments

The authors express their appreciation to Dr. Joe Vollmer, Dr. Jennifer Vollmer, Scott McCoy, Mark Williams, Ella Ybarluccea, Joel Billman, Brad Eddins, Jack Hensley, and Lynn Mortensen for their technical assistance. This research was partially funded by BASF and land was provided by Eagle Ranch and Riverbend Ranch. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the US Department of Agriculture or Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

References

Anderson, G.L., Delfosse, E.S., Spencer, N.R., Prosser, C.W., Richard, R.D., 2000. Biological control of leafy spurge: an emerging success story. In: Spencer, N.R. (Ed.), Proceedings of the X International Symposium on Biological Control of Weeds. Montana State University, Bozeman, MT, USA, pp. 15–25.

Bangsund, D.A., Leitch, A., Leistritz, F.L., 1996. Economics of herbicide control of leafy spurge (*Euphorbia esula* L.). Journal of Agricultural Research Economics 21, 381–395.

Bowes, G.C., Thomas, A.G., 1978. Longevity of spurge seeds in soil following various control programs. Journal of Range Management 31, 137–140.

Dahl, J.D., Sedivec, K.K., Faller, T.C., Stecher, D., Karn, J.F., Nyren, P.E., Samuel, L., 2001. Effects of multi-species grazing and single species grazing on leafy spurge infested rangeland (a five-year summary). Western Dakota Sheep Day 52–59.

Lajeunesse, S., Sheley, R., Duncan, C., Lym, R., 1999. Leafy spurge. In: Sheley, R.L., Petroff, J.K. (Eds.), Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis, OR, USA, pp. 249–260.

Landgraf, B.K., Fay, P.K., Havstad, K.M., 1984. Utilization of leafy spurge (*Euphorbia esula*) by sheep. Weed Science 32, 348–352.

Lym, R.G., Kirby, D.R., 1987. Cattle foraging behavior in leafy spurge (*Euphorbia esula*)-infested rangeland. Weed Technology 1, 314–318.

Lym, R.G., Messersmith, C.G., 1994. Leafy spurge (*Euphorbia esula*) control, forage production, and economic return with fall-applied herbicides. Weed Technology 8, 824–829.

Lym, R.G., Sedivec, K.K., Kirby, D.R., 1997. Leafy spurge control with angora goats and herbicides. Journal of Range Management 50, 123–128.

Markle, D.M., Lym, R.G., 2001. Leafy spurge (*Euphorbia esula*) control and herbage production with Imazapic. Weed Technology 15, 474–480.

Messersmith, C.G., 1990. Leafy spurge morphology and ecology. In: Range Weeds Revisited Symposium Proceedings. A 1989 Pacific Northwest Range Management Short Course, Spokane, WA, January 24–26, 1989.

Natural Resources Conservation Service, 1995. Soil investigation of Agriculture Research Service. United States Sheep Experiment Station headquarters range, United States Department of Agriculture, Natural Resource Conservation Service, Rexburg, ID, USA.

Olson, B.E., Lacey, J.R., 1994. Sheep: a method for controlling rangeland weeds. Sheep Research Journal 105–112 (special issue).

Olson, B.E., Wallander, R.T., 1998. Effect of sheep grazing on a leafy spurge infested-Idaho fescue range site. Journal of Range Management 51, 247–252.

Olson, B.E., Wallander, R.T., Thomas, V.M., Kott, R.W., 1996. Effect of previous experience of sheep grazing leafy spurge. Applied Animal Behavior Science 50, 161–176.

Taylor, J.B., Seefeldt, S.S., Thelen, T.M., 2005. The use of short-duration intensive sheep grazing to increase sheep utilization of leafy spurge (*Euphorbia esula* L.). Journal of Food, Agriculture and Environment 3, 316–319.

Walker, J.W., Hemenway, K.G., Hatfield, P.G., Glimp, H.A., 1992. Training lambs to be weed eaters: studies with leafy spurge. Journal of Range Management 45, 245–249.

Walker, J.W., Kronberg, S.L., Al-Rowaily, S.L., West, N.E., 1994. Comparison of sheep and goat preferences for leafy spurge. Journal of Range Management 47, 429–434.

West, N.E., 1983. Western intermountain sagebrush steppe. In: West, N.E. (Ed.), Ecosystems of the World 5: Temperate Deserts and Semi-deserts. Elsevier, New York, pp. 351–397.